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Title: Arctic benthos biogeochemistry in E3SM: progress and applications

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Arctic benthos biogeochemistry in E3SM: progress and applications

Nicole Jeffery, Mathew Maltrud, Jon Wolfe, Sean Mitchell and members of InteRFACE

RGMA High Latitude Webinar Sept 16, 2021

E3SM
Energy Exascale Earth System Model

Interdisciplinary Research for Arctic Coastal Environments

RGMA (+MSD): How does changing seasonality in riverine fluxes and landfast ice persistence impact marine ecosystems in Alaska's arctic coastal waters and shelf seas, and how might this inform fisheries and human subsistence activities?

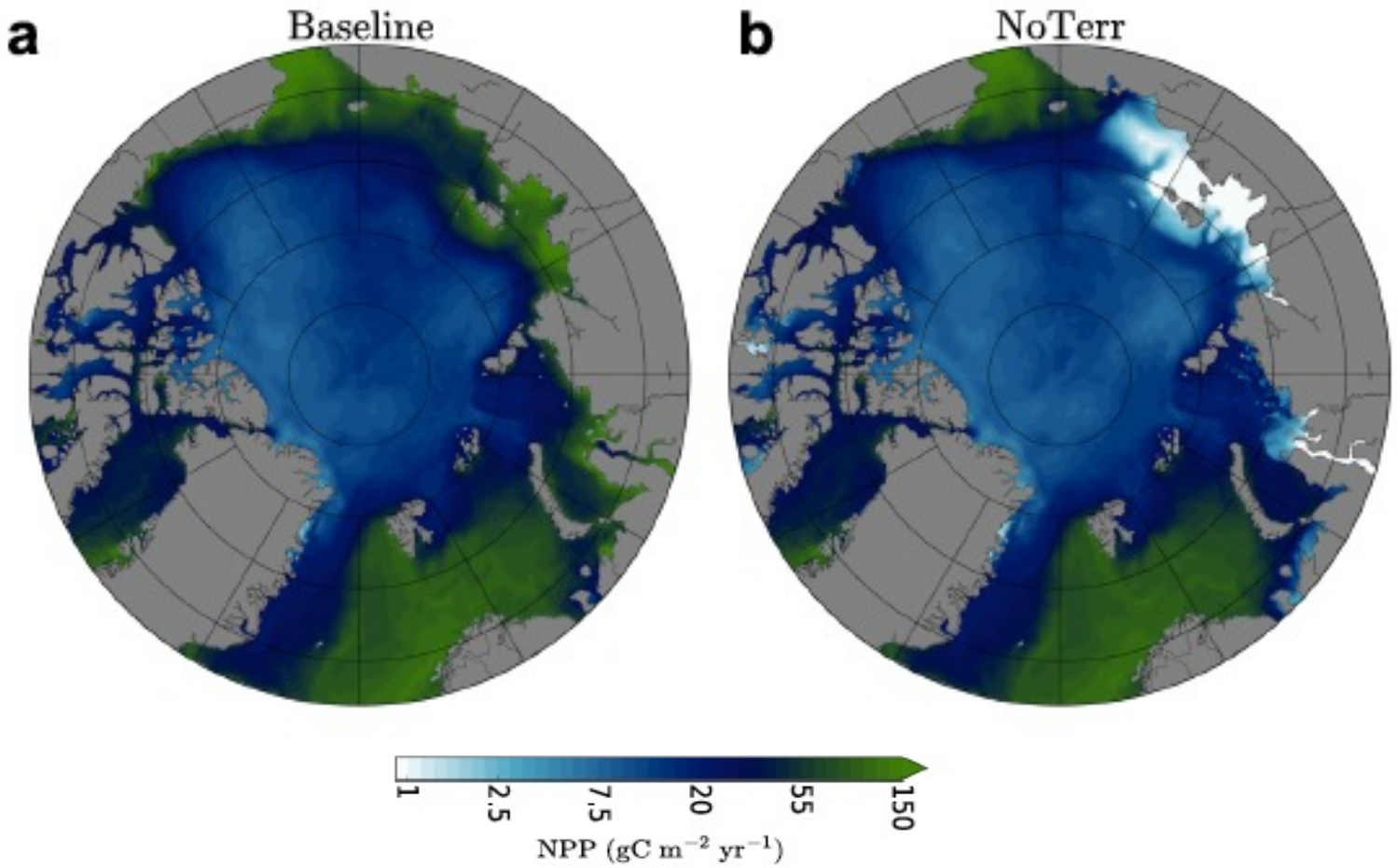
ESMD (+MSD): How will the structure and productivity of the marine ecosystem of the Bering, Chukchi and Beaufort Seas respond to future climate conditions, and how might this inform commercial fisheries?

Biogeochemistry: Development of a benthic (seafloor) BGC submodule in MPAS-O & E3SM for Arctic coastal and shelf waters

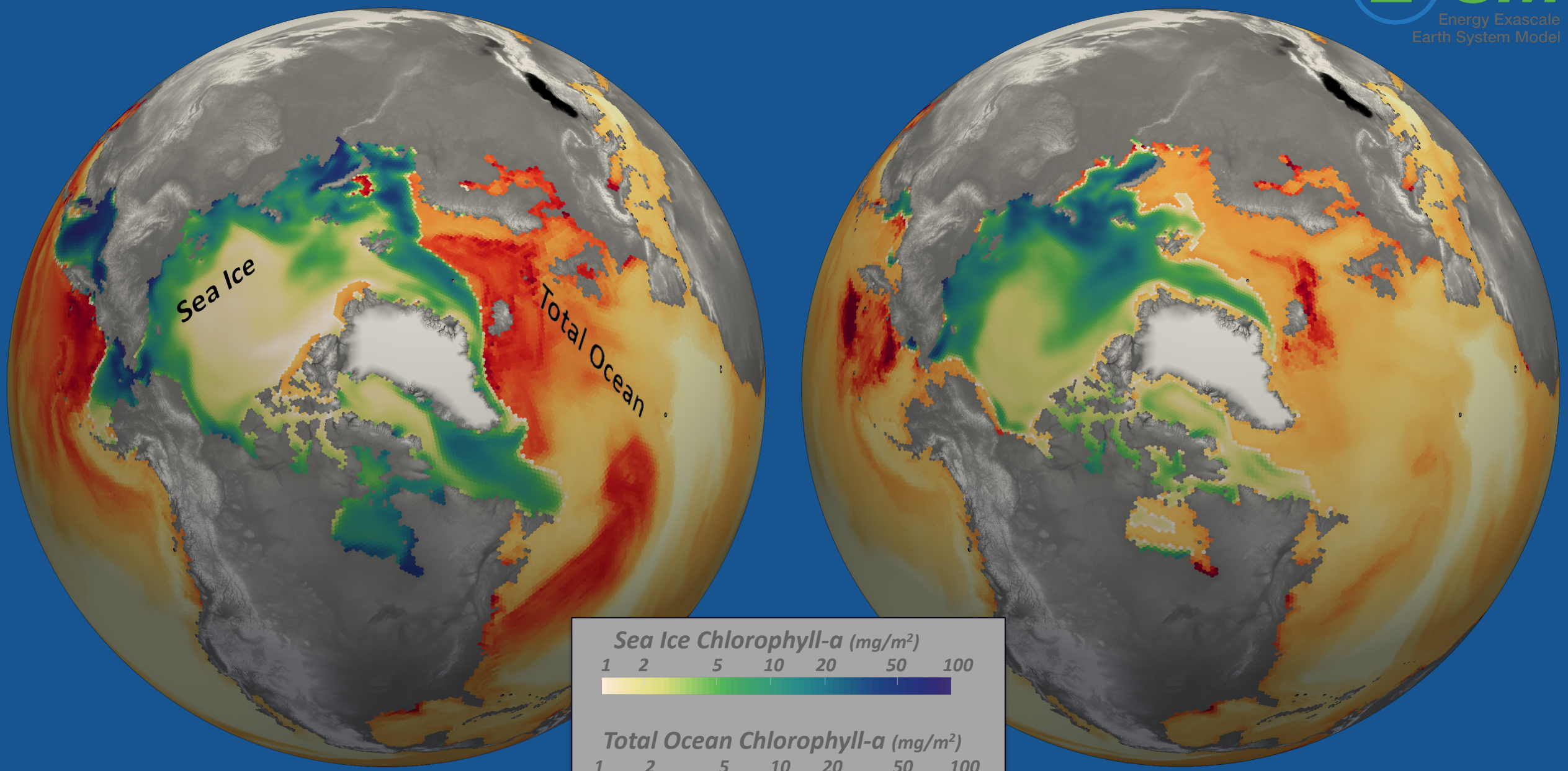
Motivation 1

"Around one third of current Arctic Ocean primary production sustained by rivers and coastal erosion"

Terhaar et al. 2021
Nature Communications



Motivation 2

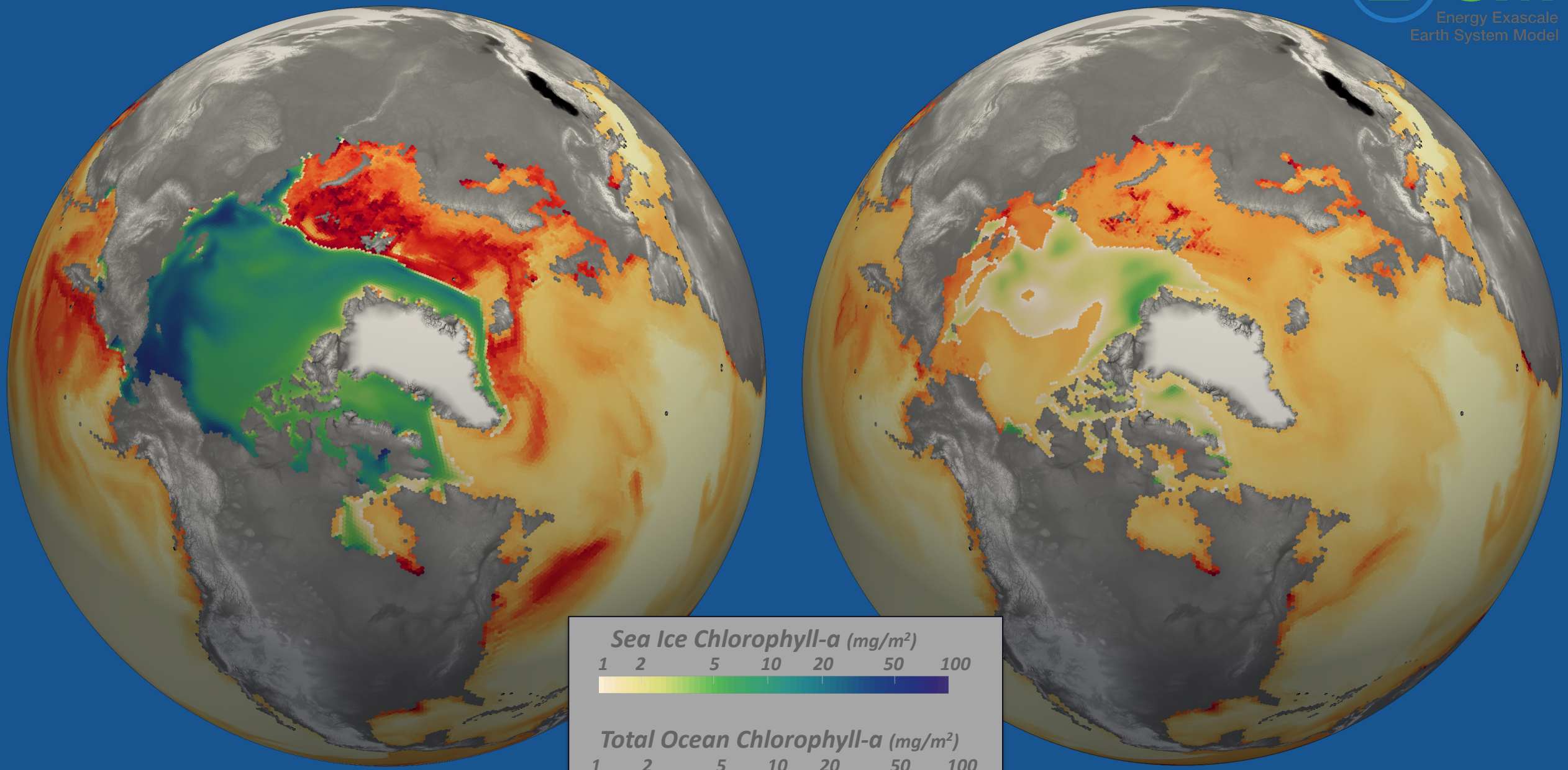


E3SM
Energy Exascale Earth System Model

2050

April

June

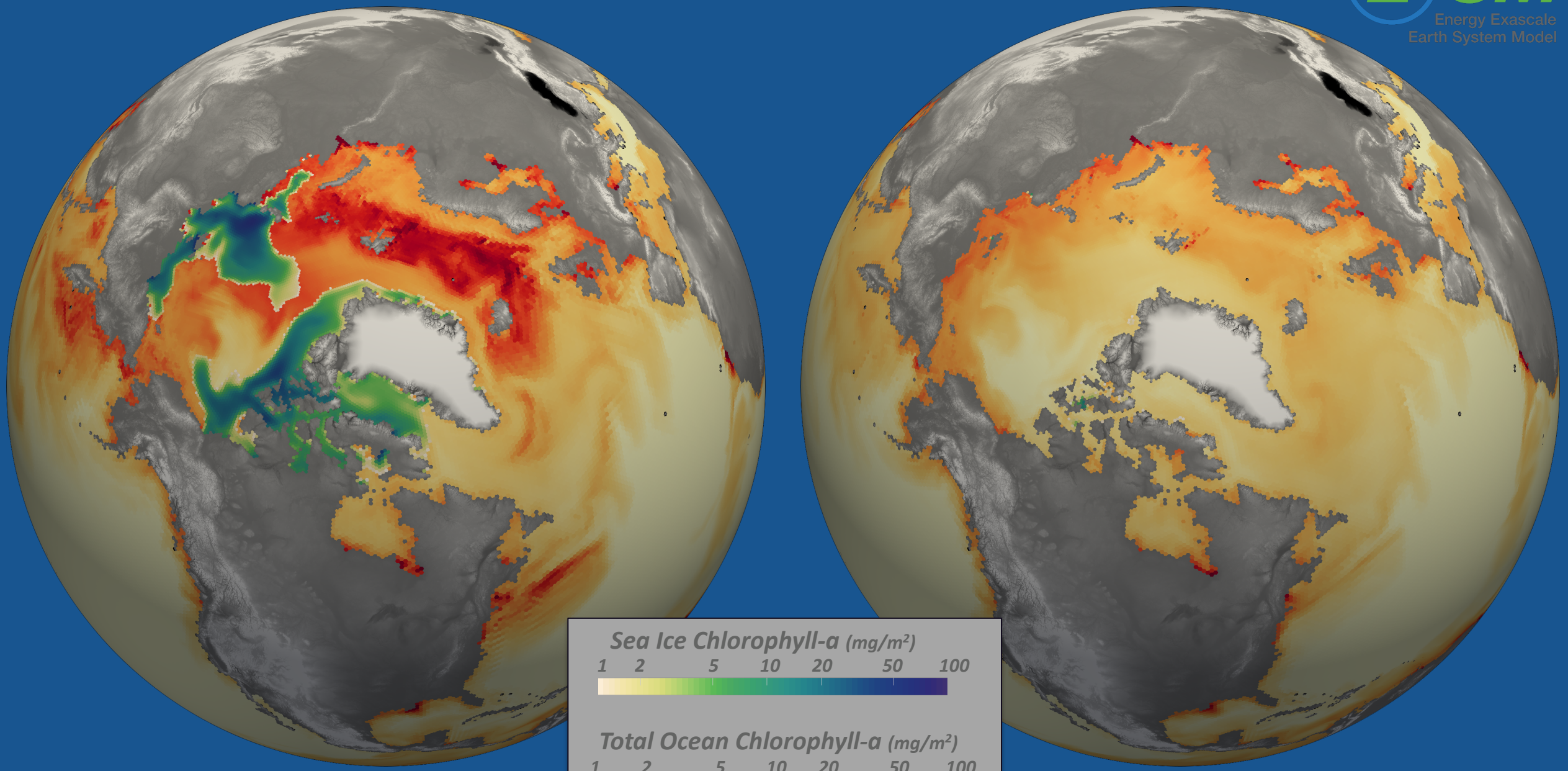


E3SM
Energy Exascale Earth System Model

2070

April

June



E3SM
Energy Exascale Earth System Model

Mat Maltrud, LANL

Arctic Food Web and the Ocean Benthos

Arctic Food Web Scenarios

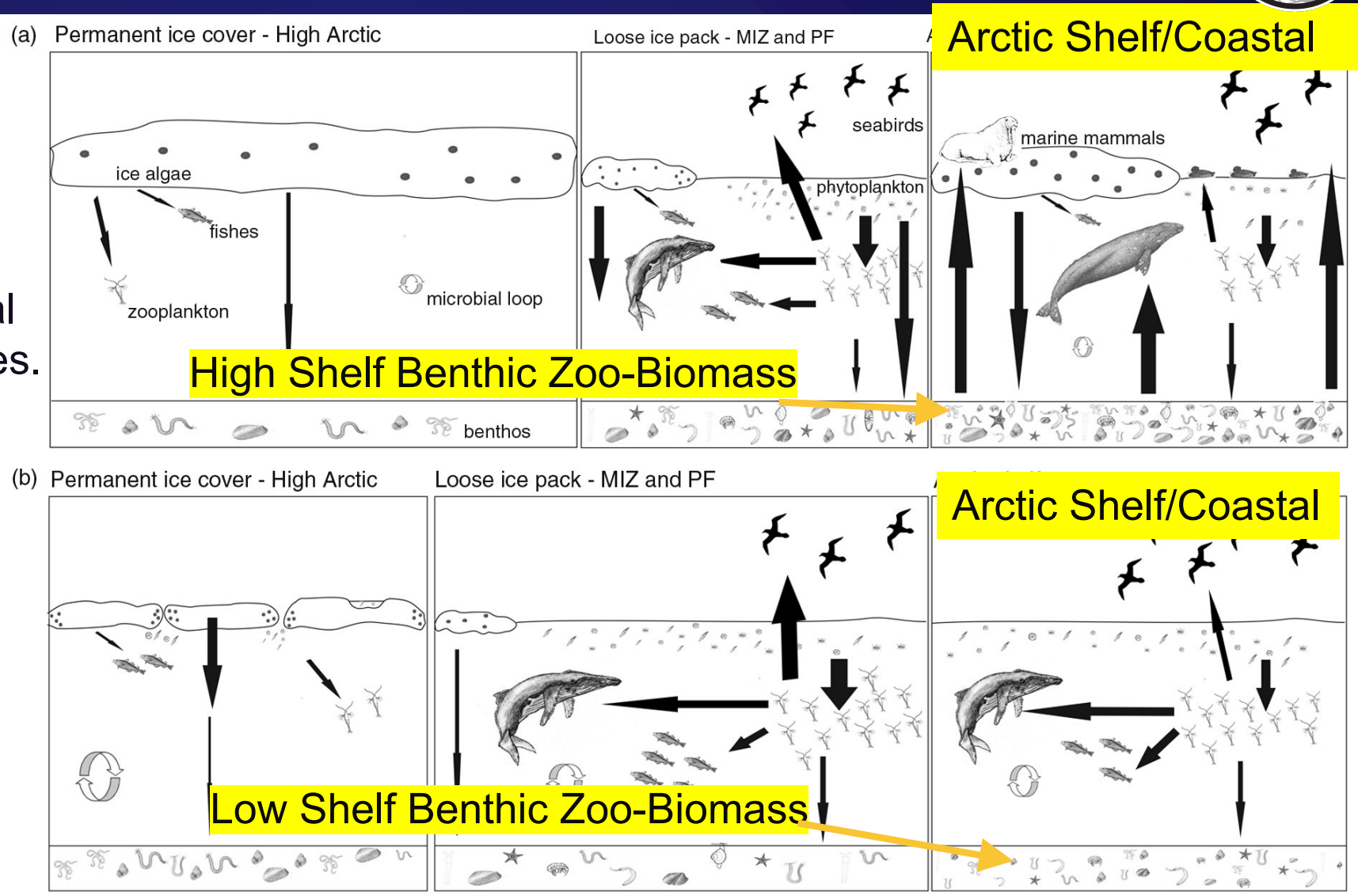
(a) Present Day:

Ice and ocean primary producers support a rich benthic biomass particularly in the shelf and coastal Arctic influenced by land processes.

(b) Future Estimate:

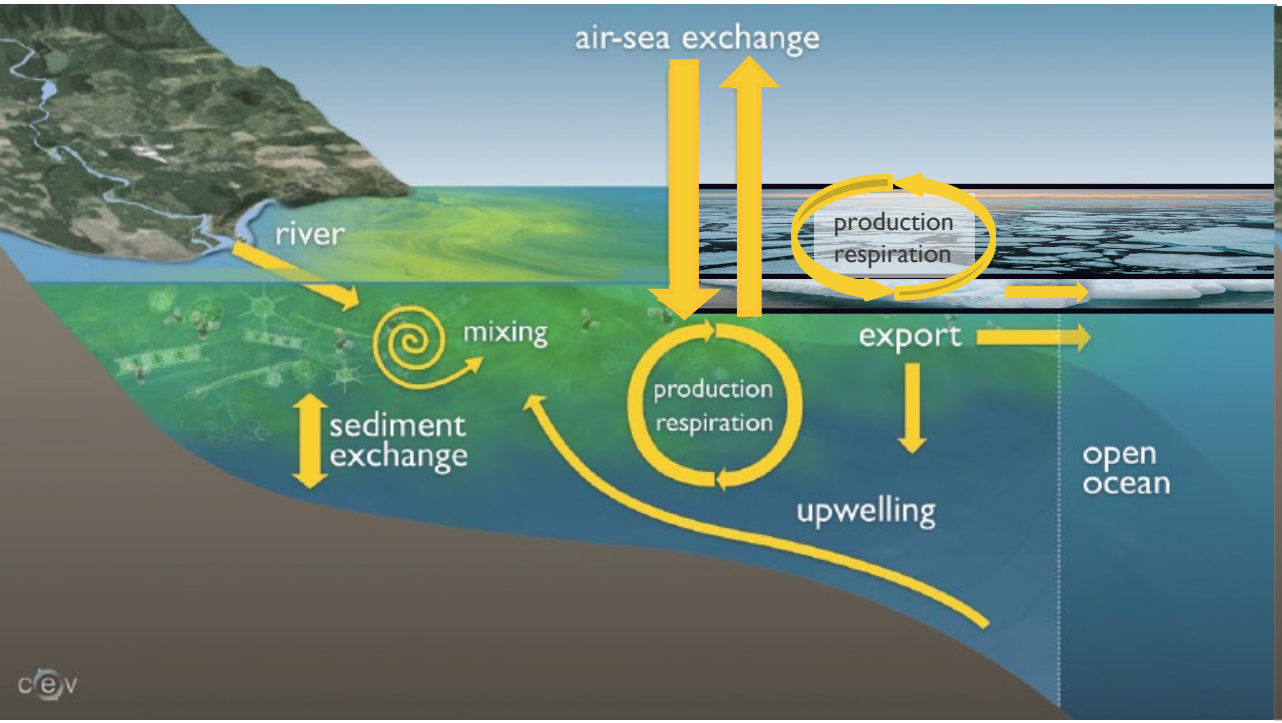
Loss of sea ice, changes in stratification, & changes in phytoplankton species reduce primary production fluxes to the benthos at the expense of many apex predators.

How will changes in coastal processes alter this scenario?



Kedra et al 2015

Coastal Carbon Pools



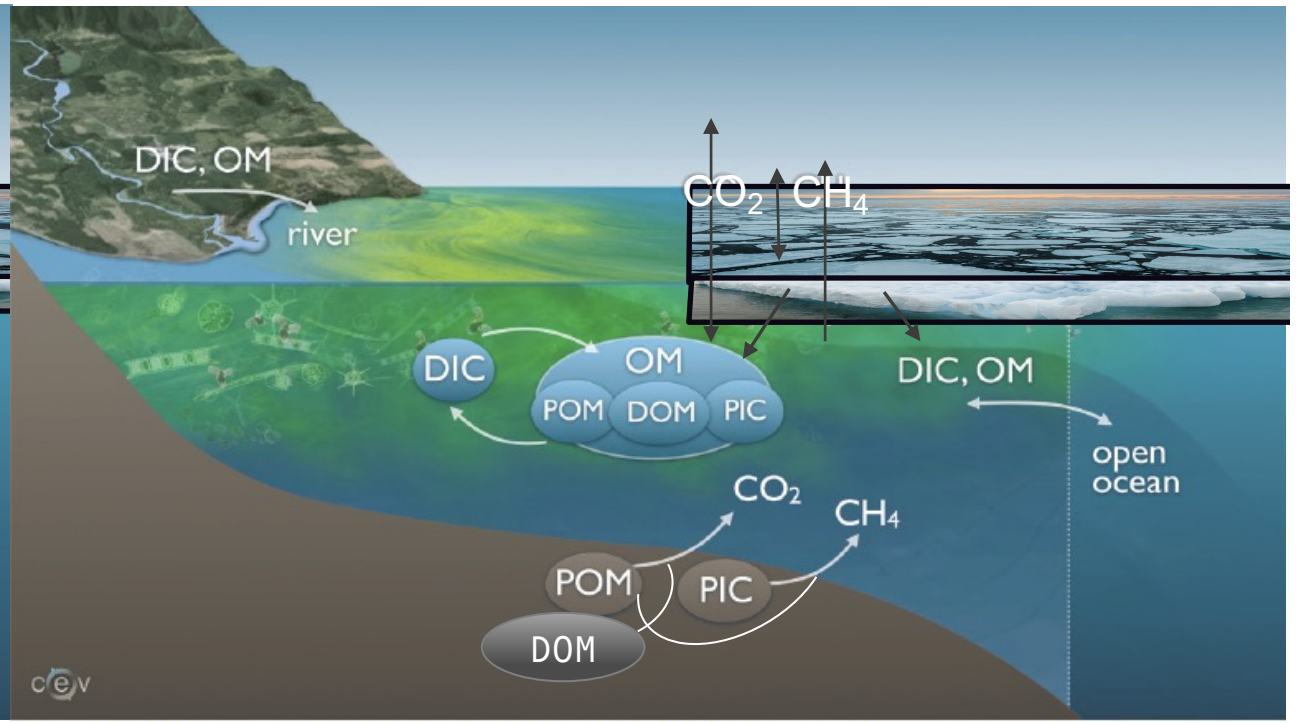
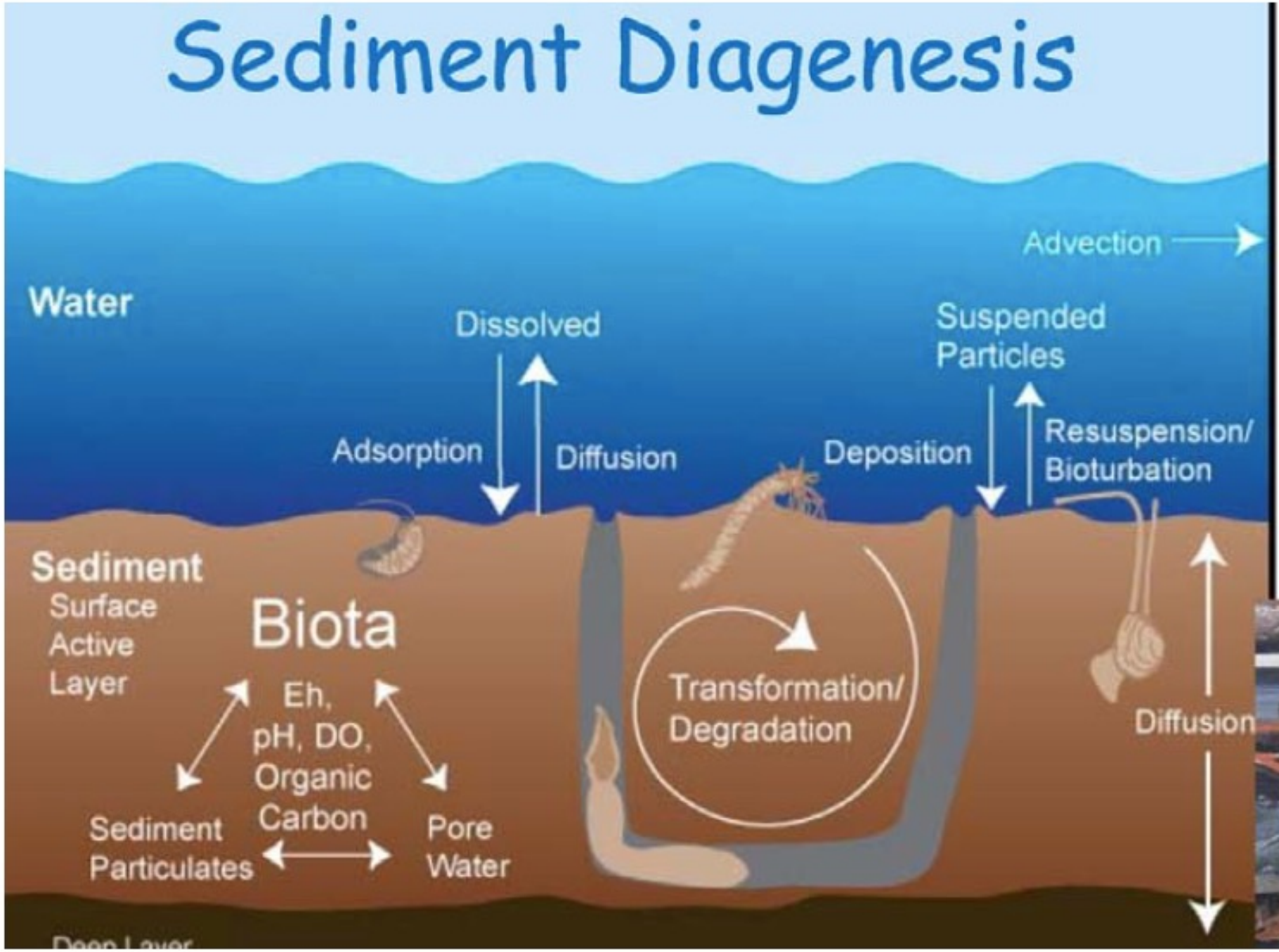
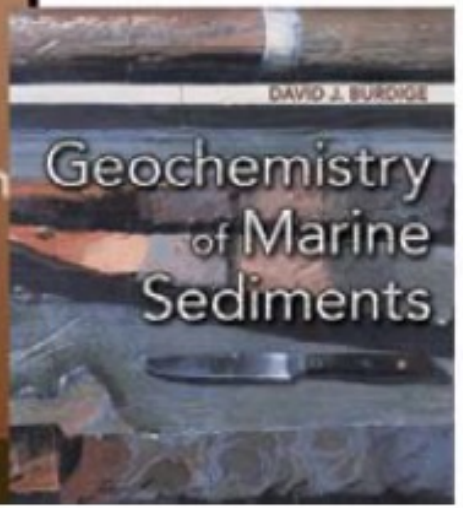


Figure 16.2. Major Coastal Carbon Pools and Fluxes. (a) Carbon in various forms (e.g., CO_2, carbon dioxide; CH_4, methane) is transferred among different pools and exchanged across interfaces between land, air, and ocean in coastal regions. **(b)** Carbon forms include dissolved inorganic carbon (DIC), organic matter (OM), particulate organic matter (POM), dissolved organic matter (DOM), and particulate inorganic matter (PIC). [Figure sources: Simone Alin, National Oceanic and Atmospheric Administration; Hunter Hadaway, University of Washington Center for Environmental Visualization; and Katja Fennel, Dalhousie University.]

Chapter 16: Coastal ocean and continental shelves: In Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report (2018)

Sediment Diagenesis





Ocean Benthos Diagenetic Model: Reactive Processes

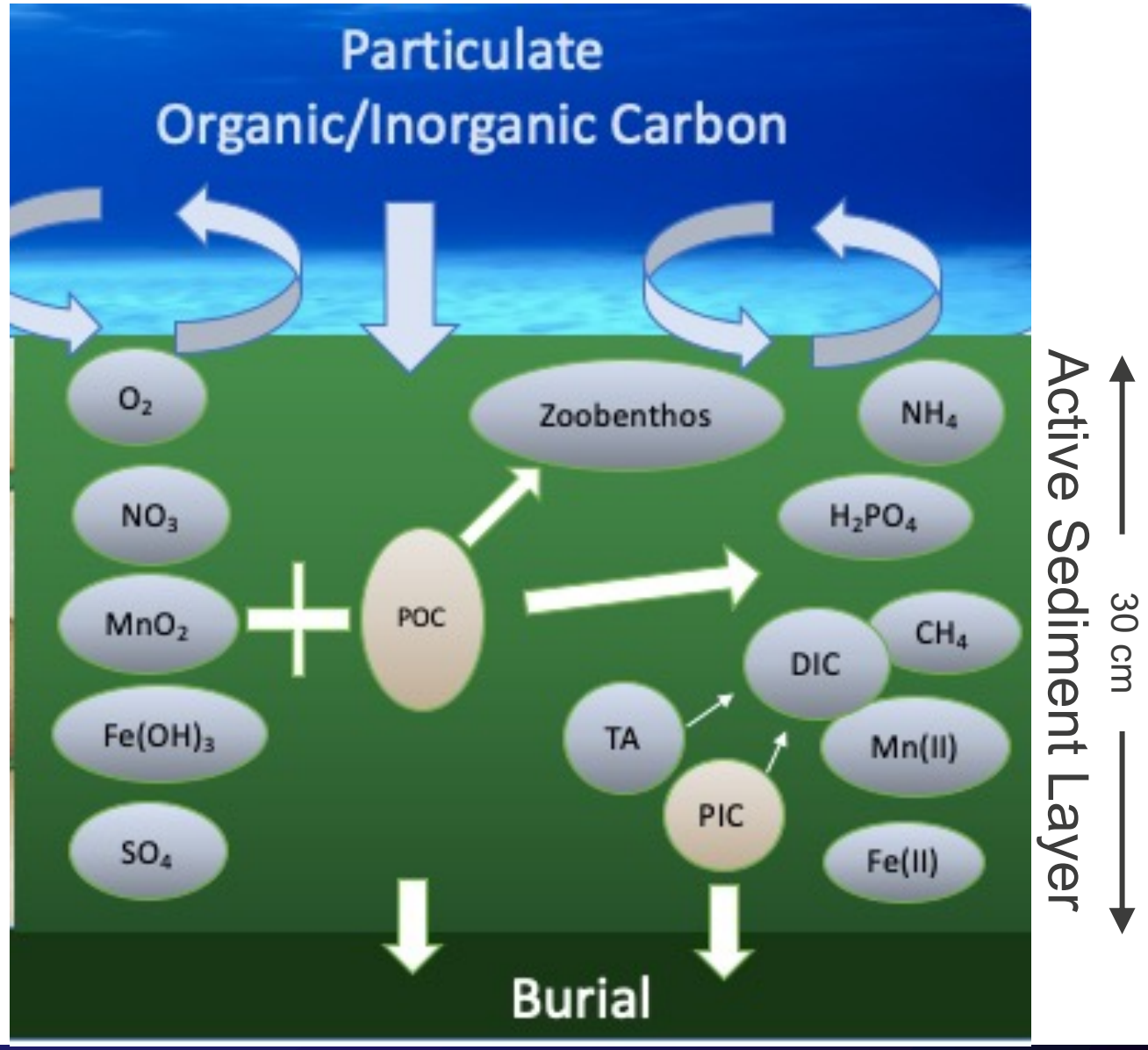
Organic matter decomposition fuels the reactive transformations in the sediments

Microbiologically mediated, but microbial biomass is not explicit in the kinetics.

Rather kinetics follow the preferred oxidants: O_2, NO_3, MnO_2, $Fe(OH)_3$, and SO_4

Lastly, when oxidants are depleted, POM decomposes through methanogenesis (CH_4).

Total of 35 solid/solute tracers



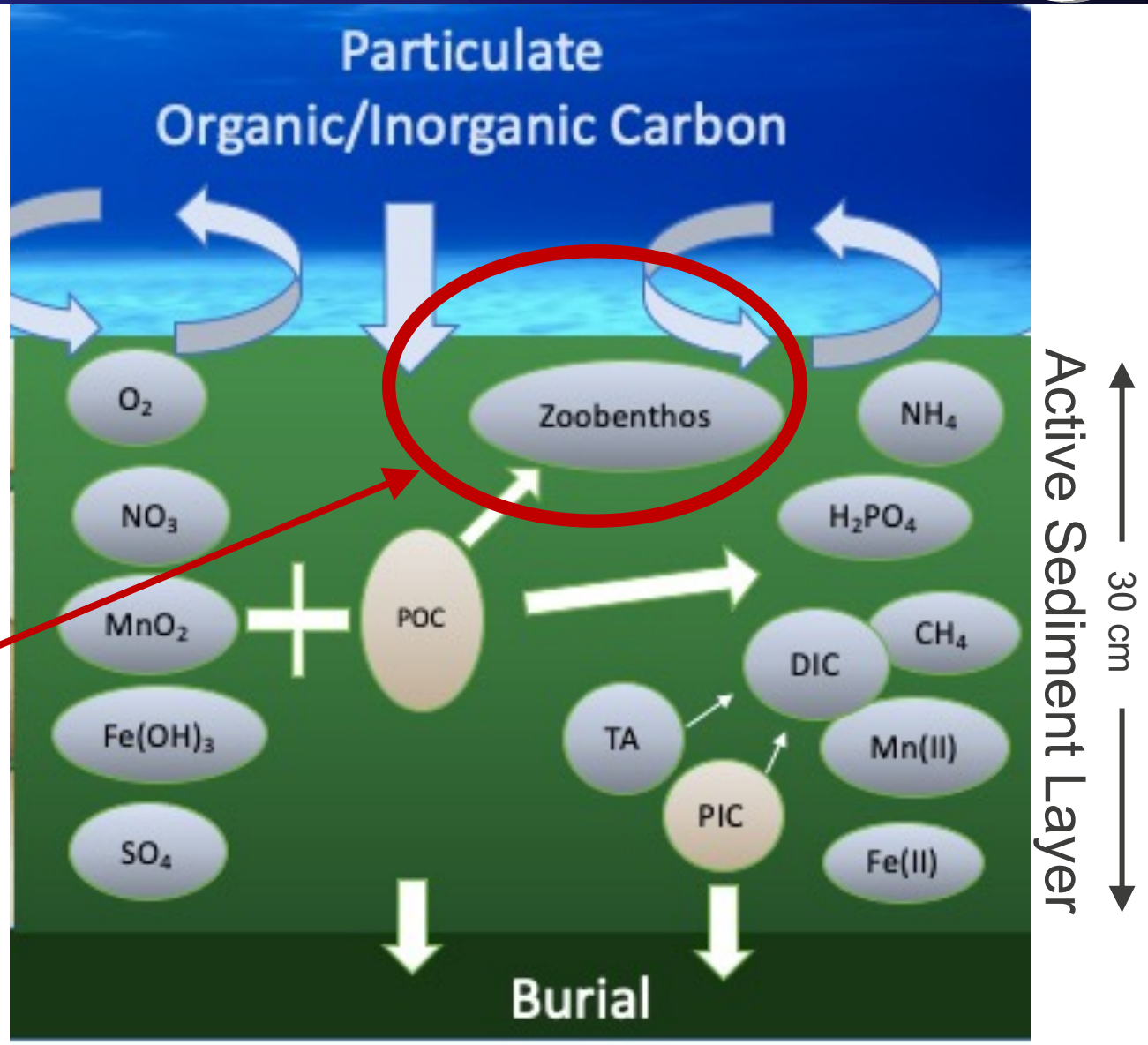
Ocean Benthos Diagenetic Model: Reactive Processes

Particulate inorganic carbon dissociation: Calcite, aragonite and 15% mg-calcite

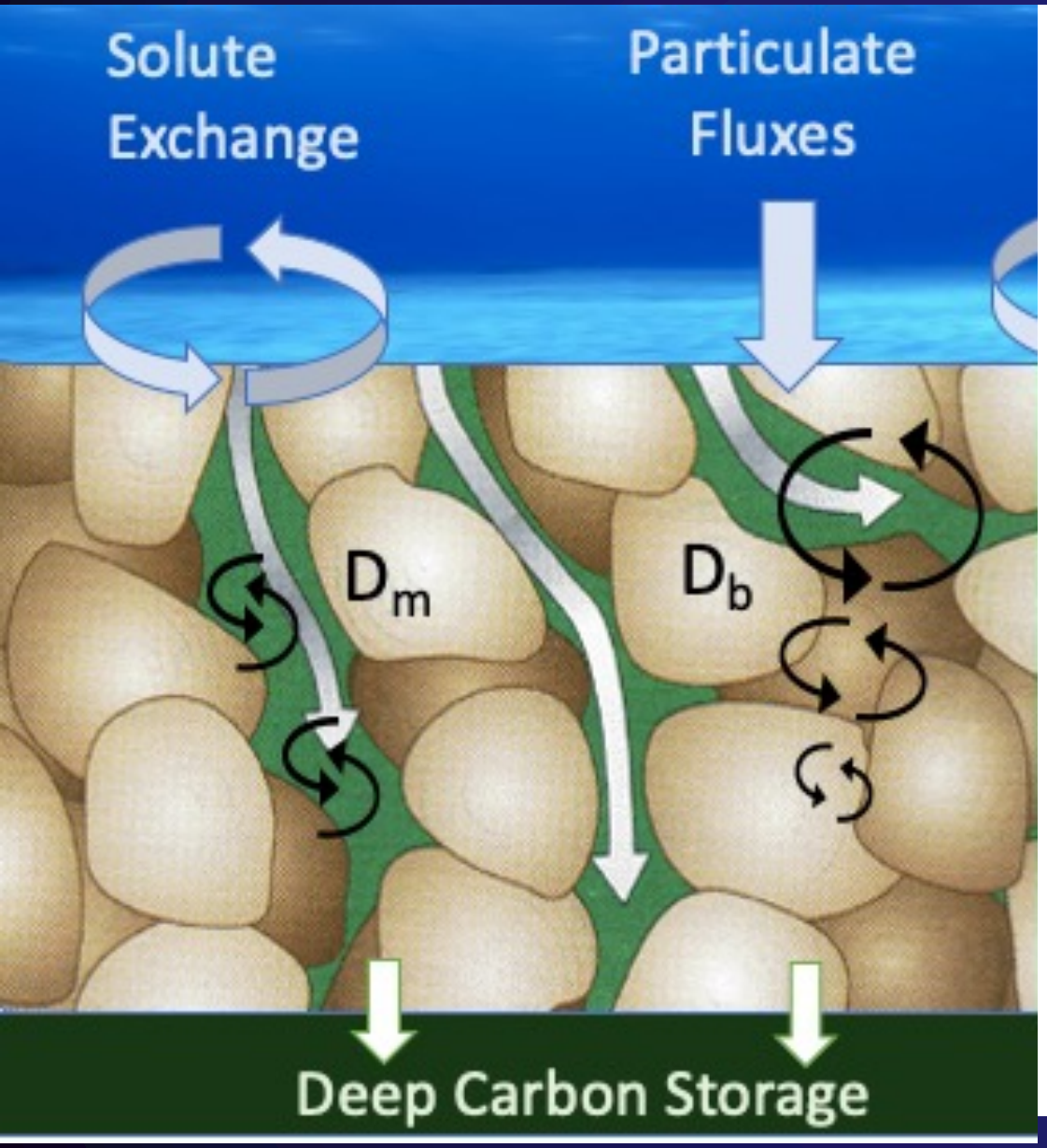
Also included but not depicted are 19 secondary reactions

Still to do:

- Meio/macro–fauna biomass model (food security implications)
- macroalgae (E3SM)



Ocean Benthos Diagenetic Model: Mixing and Transport



30 cm active layer (30 variable resolution grid levels: 1 mm to ~5 cm)

Sinking **particulate fluxes** =
sedimentation + *precipitation*

Diffusive exchanges of solutes with ocean bottom waters

Interior mixing:

D_m = molecular diffusion (corrected by tortuosity) of *solutes*

D_b = Biodiffusion of *solids* and *solutes*

Arkona Basin, Baltic Sea Test Case

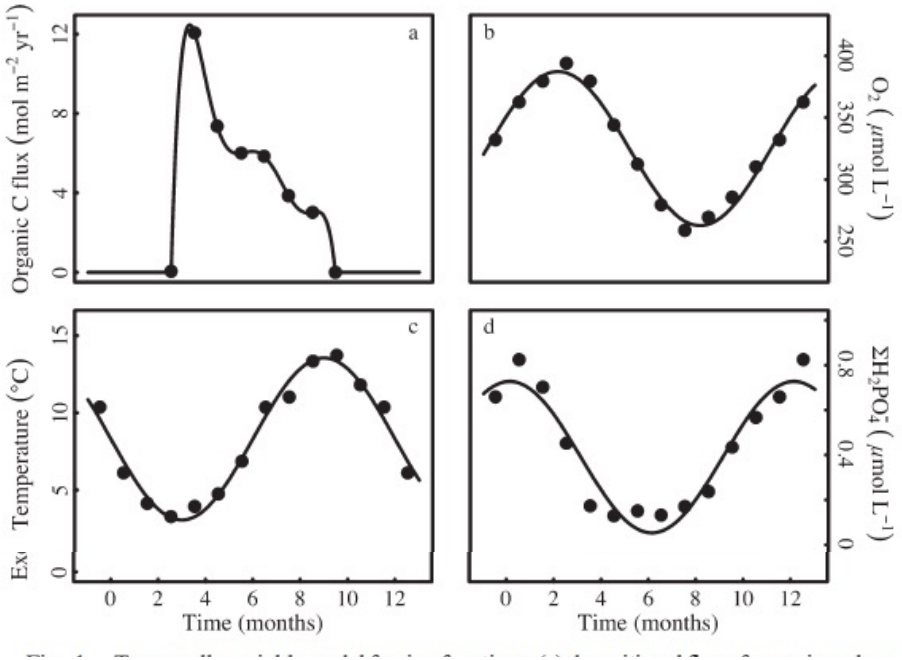
MPAS-O BGC Benthic Model

(Based on Reed et al. 2011 + carbonate chemistry Krumins et al 2013)

Arkona Basin:

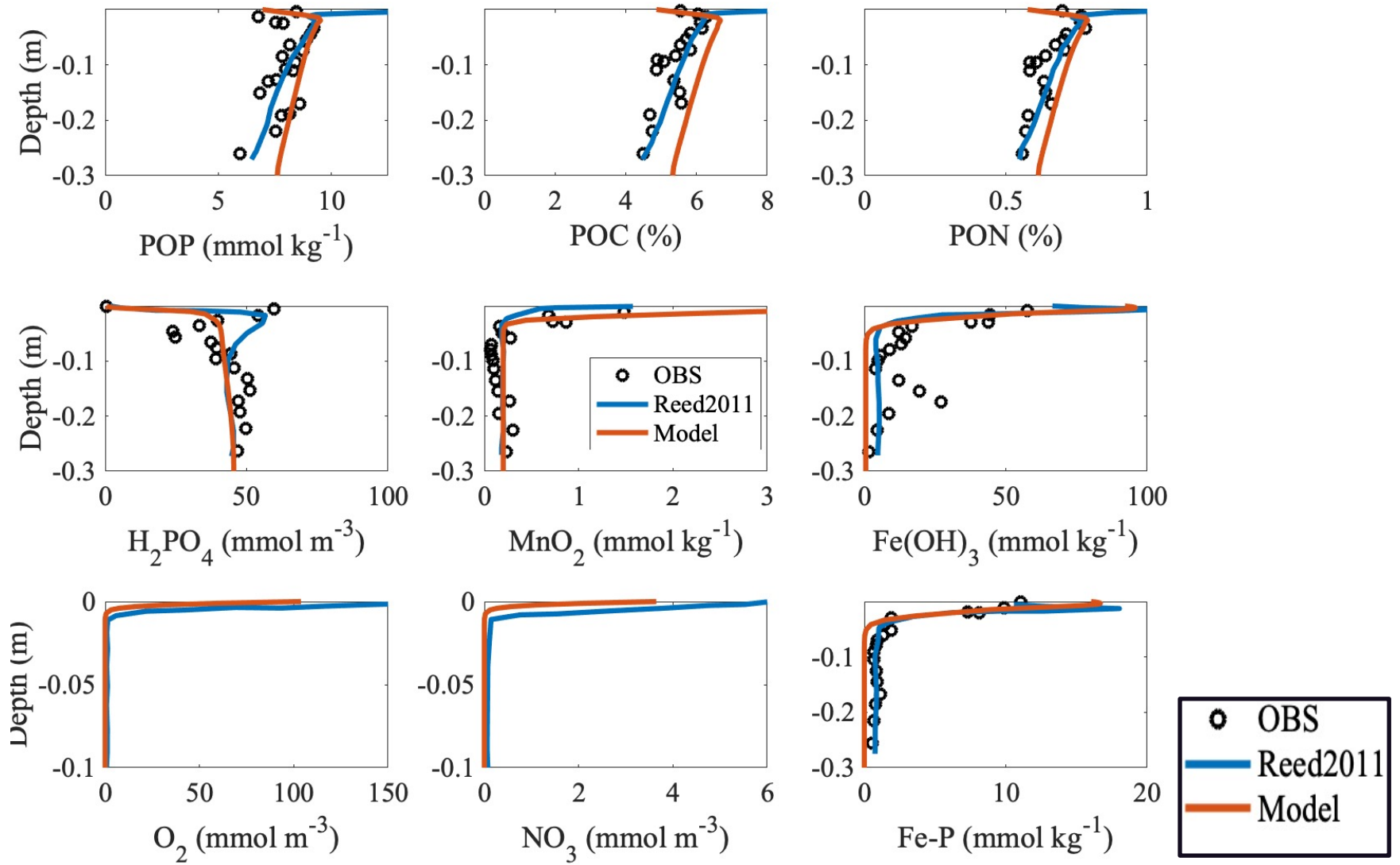
- Data rich – Sediment/pore water/ocean data (Mort et al. 2010)
- Reed et al. model output (2011).
- 30 cm active sediment layer
- Typical ocean depths about 50 m
- Increasing hypoxia

Upper boundary seasonal forcing: ocean bottom water conditions



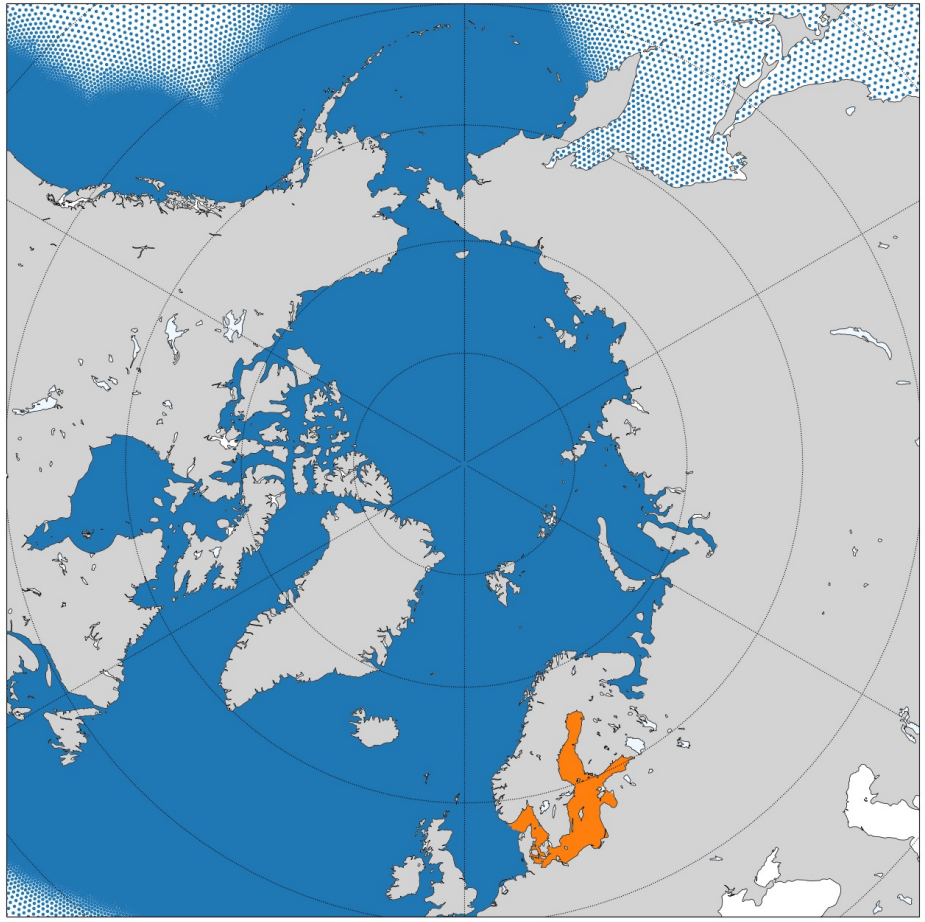
Model Validation

100s + years of spin-up + Experiment: After 80 years of observed POC flux increase

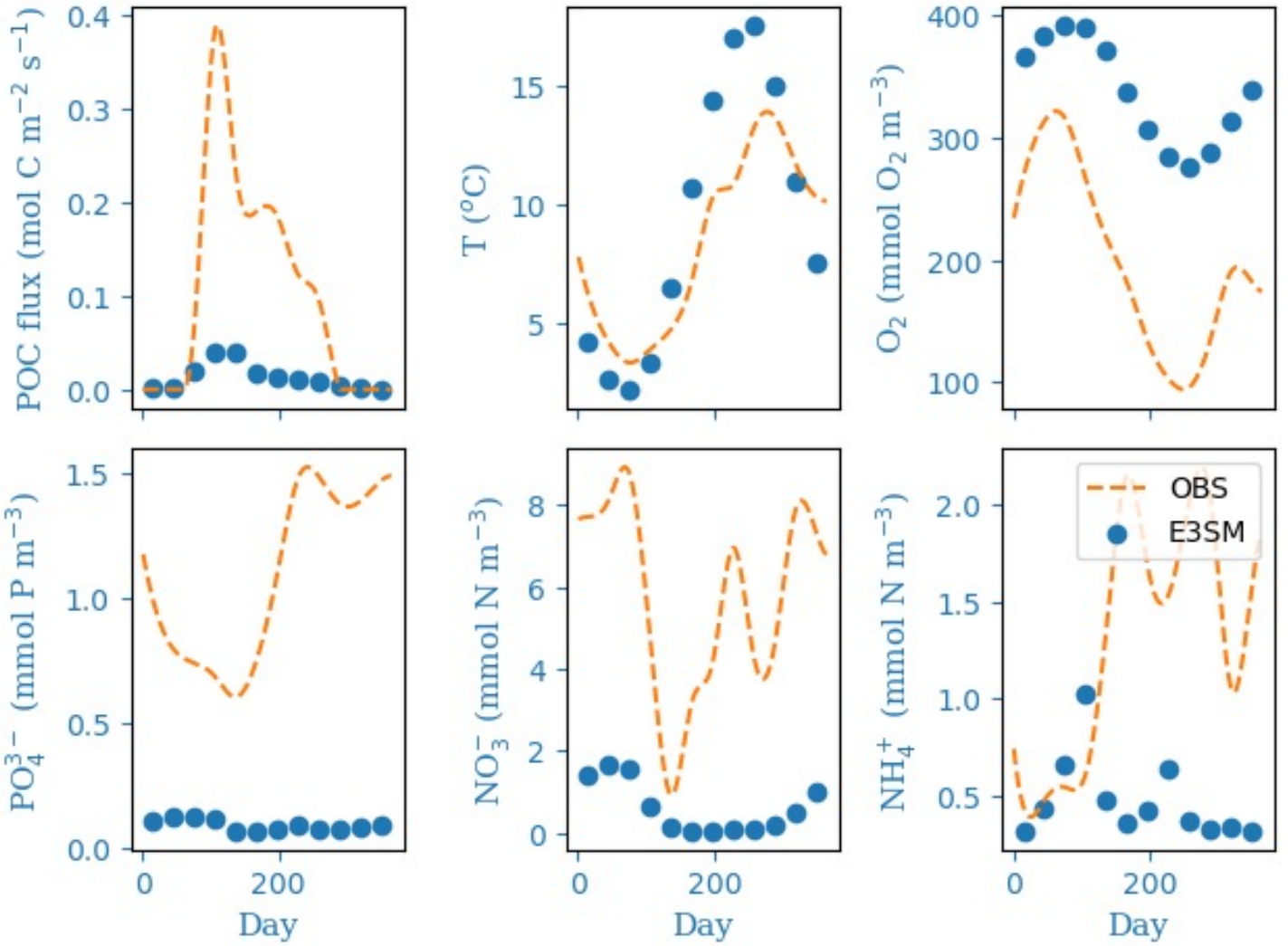


E3SM Spin-up: Using v1 ocean bottom climatology

Baltic Sea



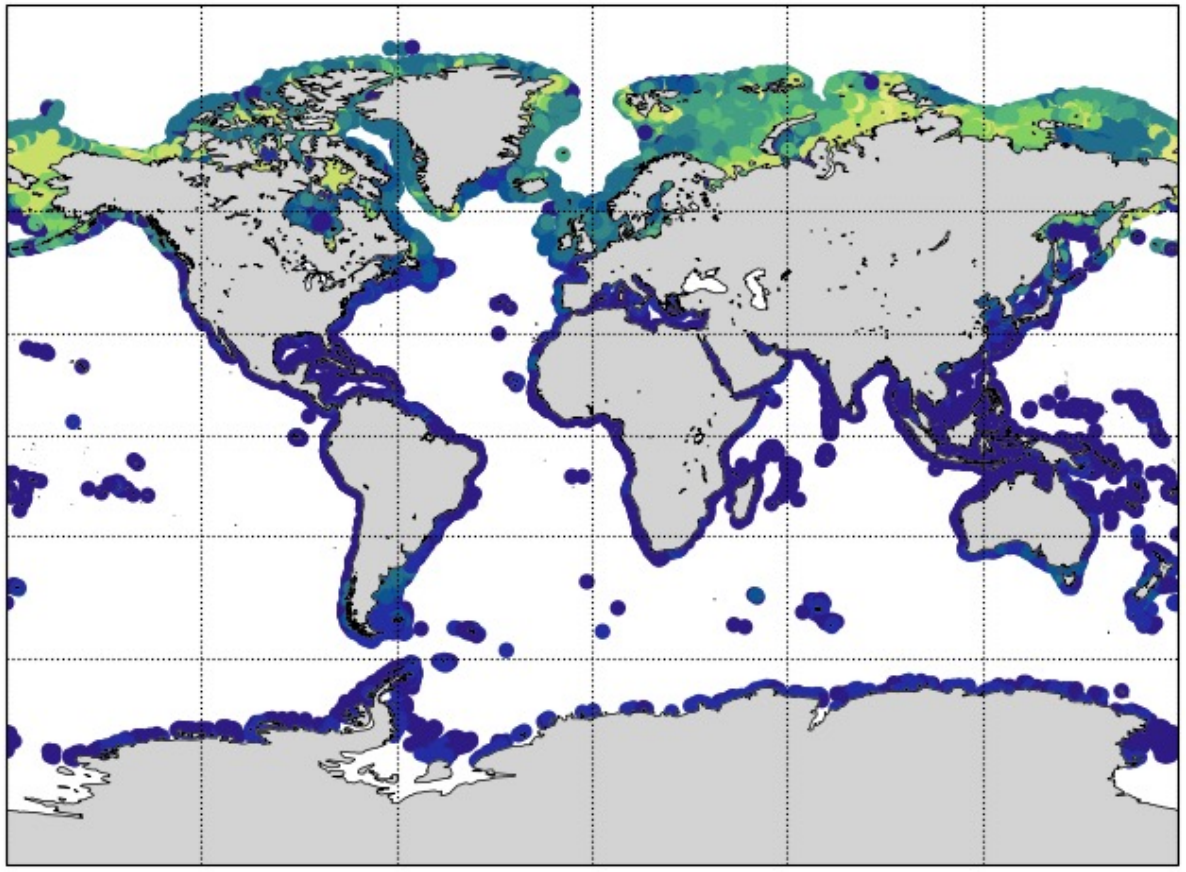
Biases in E3SMv1.1 ocean bottom conc/fluxes

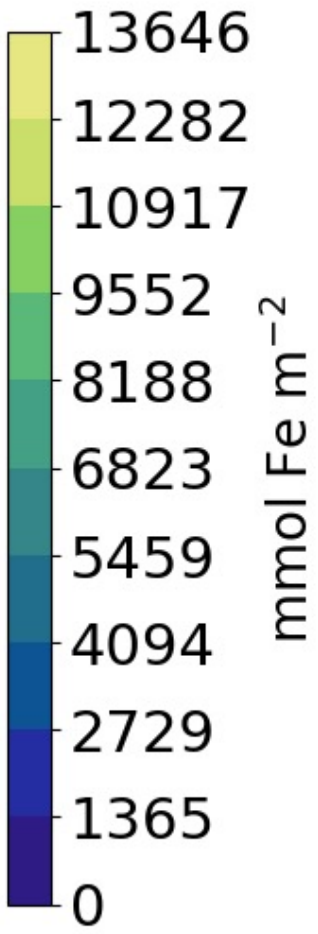


Global Simulations After 100 years: Benthos region (< 400 m isobath)

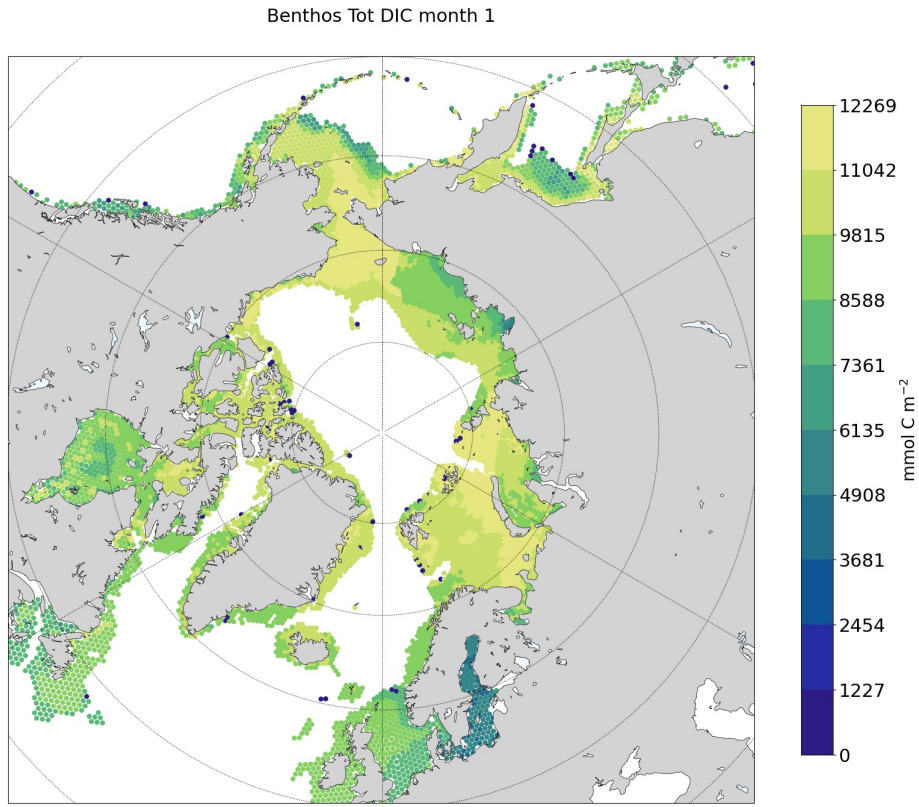
Integrated over the 30 cm active sediment layer

Benthos Tot Fe (mmol Fe/m^2)

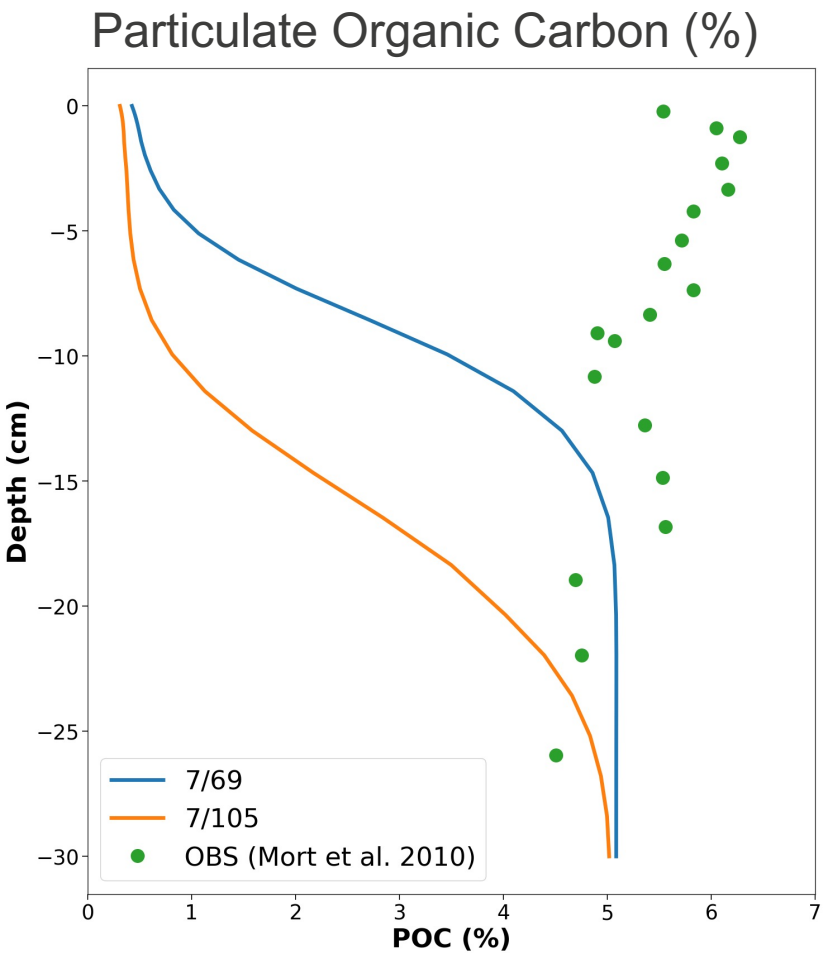


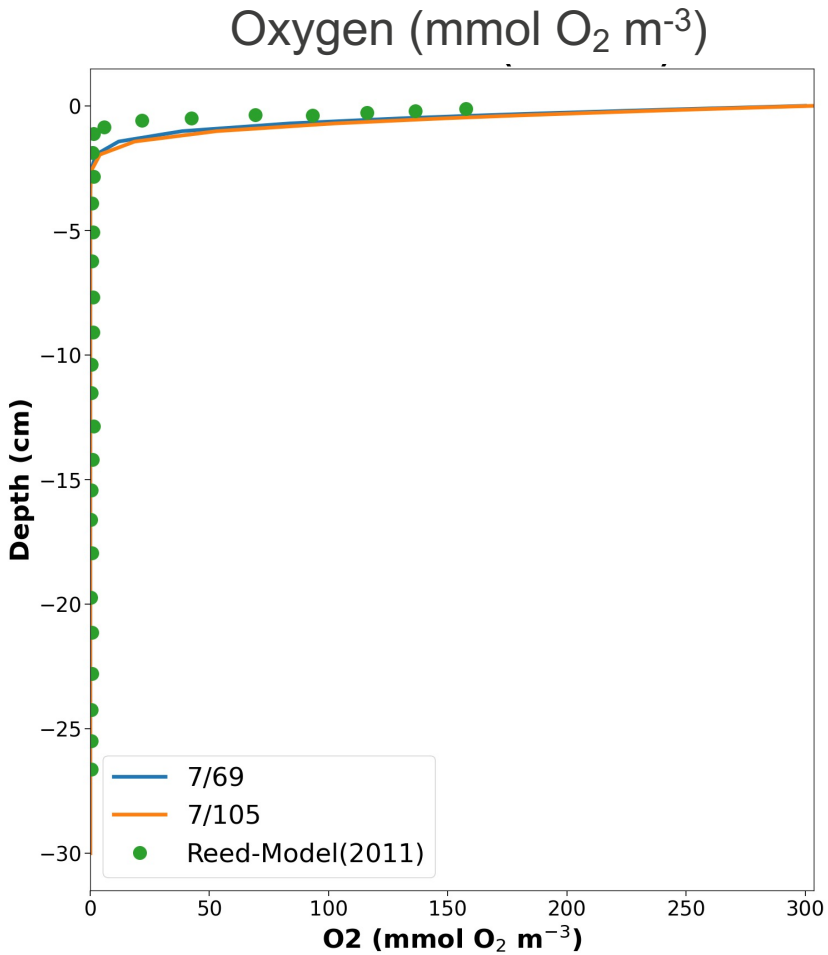


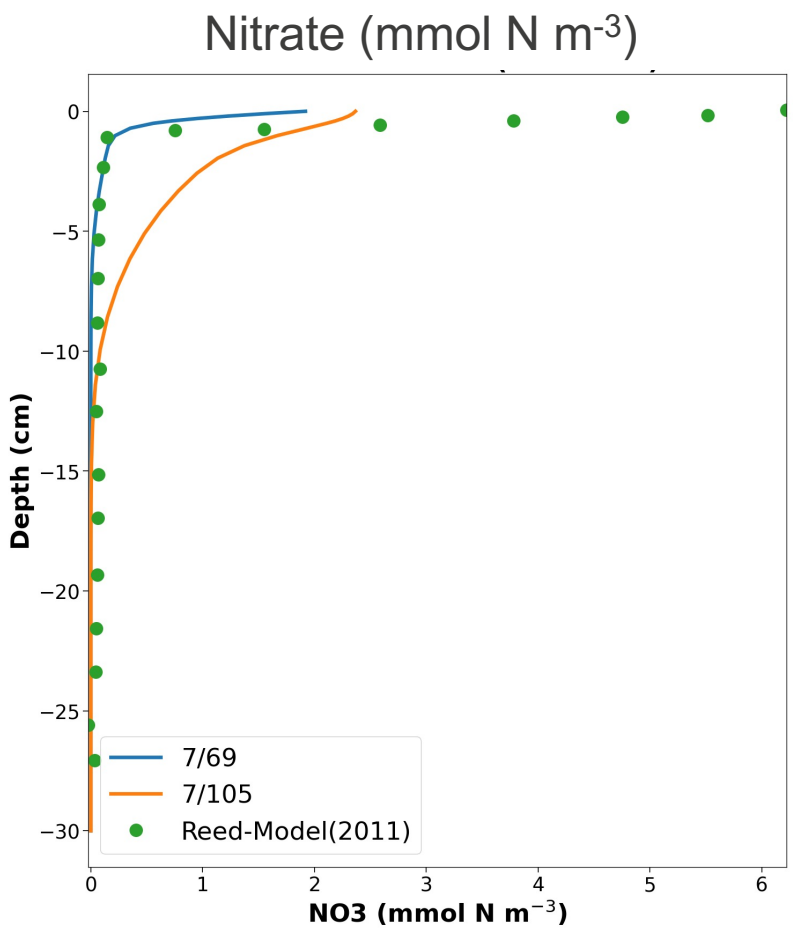
Tot DIC (mmol C/m^2)



Significant changes over 50-100 year time-scale







Summary and future work

Achievements:

- We have a working submodule of diagenesis of the ocean benthos running in E3SM

Challenges:

- Spin-up challenges – with underestimations in Arctic Primary Production in E3SM v1.1, should we wait for E3SM.v2??? Another model?
- Time-stepping challenges: reactions are stiff, sub-cycling is slow. What is our tolerance for element conservation?

Still to do, but in progress:

- Expand validation to more Arctic coastal regions
- Activate the benthos submodule in erosion/river flux sensitivity simulations for InteRFACE.
- Implement the zoobenthos portions (InteRFACE)
- Add kelp (E3SM)